

THE ROLE OF LEAD SYSTEM INTEGRATOR

by

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Executive Summary

The Department of Defense (DoD) (as well as other government agencies) has used a strategy of contracting with a Lead System Integrator (LSI) when pursuing large System-of-System (SoS) acquisition programs. A SoS acquisition program involves the purposeful integration of individual weapon systems, along with other task-oriented assets, yielding a sum greater than the constituent parts. A SoS acquisition program will typically integrate legacy systems with new weapons platforms; in some cases, however, a SoS program will completely design and integrate a new set of systems.

A SoS is most likely to attain its potential benefits if a sole entity is responsible for managing the process. In order to properly manage the risks of a SoS development, a responsible agent is needed to fulfill the role of coordinating and managing the complex effort, provide commonality across multiple weapons platforms and ensure a common vision for the program. Responsibilities can include systems engineering, architecture development, cost estimating, element selection, and SoS validation. This function is known as SoS integration. Believing that it did not have the organic managerial capability to oversee such monumental development tasks, the government has employed private contractors, which have come to be known as Lead System Integrators (LSIs), to manage the development of selected SoS programs. Due to difficulties faced by the Coast Guard's Deepwater SoS development, Congress prohibited the awarding of new LSI contracts, effective October 1, 2010, to firms that supply systems hardware for the SoS or perform an inherently governmental function (Congress 2008). Despite this prohibition, the SoS integration functions performed by LSIs remain critical if the government wishes to pursue SoS engineering programs.

The impetus for SoS development has two foundations. First, the military has adopted a new fighting doctrine known as Net-Centric Warfare (NCW). NCW attempts to leverage the advantage of information integration by distributed "sensors and shooters" to fight more effectively. NCW is characterized by complete battlefield awareness, self-synchronization of forces, and the overwhelming and precise application of force. This doctrine potentially reduces individual weapon system requirements but raises new issues

such as communication system vulnerabilities. Second, many military assets are approaching the end of their originally-intended lifespan and require replacement. This situation stems from a lack of military development during the 1990s, combined with the increase in military requirements since the terrorist attacks of 9/11.

System-of-Systems acquisition provides the crosslink between the DoD's change of military doctrine and its need to modernize its current forces. A SoS development provides the DoD with the unique ability to simultaneously field the full range of capabilities that it seeks in its next generation of military units. The integrated nature of the SoS, centered around an extensive communications network, lays the groundwork for complete implementation of NCW.

System-of-Systems Engineering (SoSE) offers the military two significant potential benefits. First, SoSE enhances the value of the end product by purposely synthesizing the attributes of a group of units into something that is greater than the sum of the individual parts. Second, SoSE, by taking a holistic view of the project, has the potential to improve development decision-making by better valuing overall development tradeoffs. In a SoS framework the SoS development output is maximized, as opposed to individual assets. In order to achieve optimal SoS performance within affordability constraints, SoSE requires development tradeoffs among the assets that comprise a given SoS.

SoSE differs from traditional engineering in significant ways. Traditional engineering seeks to optimize the performance of a single system, given specific end-requirements. SoSE attempts to develop a certain overall mission capability. SoS has two unique challenges not faced by traditional engineering. First, a SoS has a theoretically infinite lifespan as elements come and go in the SoS as it evolves. As long as the mission capability is supported, the SoS changes to continue to fulfill its role, even as the elements that constitute the SoS can be continuously replaced. Second, a SoS has undefined requirements—within cost, schedule and technology constraints. Without a specified end point that encapsulates firm performance requirements, engineers have difficulty making explicit tradeoffs in functionality. Traditional engineering practices are not adequate to develop a truly integrated SoS.

The DoD faces many challenges that may undermine effective SoS development: greatly broadened military requirements, since the terrorist attacks of 9/11; impending budget constraints, stemming from the need to increase federal mandatory spending programs as baby boomers enter retirement; the inadequate capability and capacity of the current acquisition workforce to undertake SoS development programs; and the consolidation of the defense industry, which has significantly reduced competition and eliminated many independent systems engineering firms (primarily through acquisitions by the weapon systems producers). SoS specific challenges include an inconsistent understanding of the term SoSE by the acquisition workforce (including the role of cost in the systems engineering analyses); the lack of a codified approach to SoSE, a function of the newness of the process; the interconnected nature of SoS development, which if not handled properly could lead to systemic failure, as disaster in one portion can have deleterious ripple effects throughout the entire SoS; ensuring adequate adaptability, so the SoS is flexible enough to meet future needs but provides enough stability to be a base for future design; the scale of development that necessitates the simultaneous development of a large number of assets, each of which would have traditionally been viewed as a major acquisition program; and, finally, budget instability, which is a constant challenge to DoD programs but to which SoS development is particularly susceptible.

The LSI, like a traditional prime contractor, must oversee technological maturity and subsystem development, as well as make decisions regarding tradeoffs within the context of the entire program. LSIs, however, have been given broad, government-like authority to execute acquisition programs that include development of individual system requirements, contracting for their development and procurement, and coordination of development schedules and efforts. The degree of authority and responsibility given to an LSI, however, depends upon the program in question. Regardless of the authority the government delegates to the LSI, the government is still responsible for the program and must oversee the actions of the LSI and retain final decision authority.

Although the government could potentially perform the SoS integration function, its acquisition workforce lacks the number of skilled personnel that this effort requires.

Consequently, the government chose to employ LSIs for its two largest SoS programs: the Army's Future Combat Systems and the Coast Guard's Deepwater.

Congress has defined two types of LSI contracts. A LSI with SoS system responsibility is a prime contractor that is primarily responsible for developing or producing the SoS, but will subcontract much of the actual work. In this case, the LSI is responsible for the delivery of the completed, integrated system to the government. A LSI without SoS system responsibility is a prime contractor that is delegated government-like authority to perform what are typically considered inherently governmental functions. Although Congress has defined LSI in only two ways, the relationship between the government and its chosen LSI can vary considerably, depending on how the contract is structured.

A principle fear stemming from use of a LSI is that the entity infringes upon inherently governmental functions. Critics warn that by awarding LSI contracts, the government avoids its primary responsibility, without being able to provide adequate oversight of the LSI. Ultimately, they argue, the LSI has a strong incentive to take actions beneficial to the firm, at the expense of the government's interests, e.g., regarding make/buy decisions on elements of the system and shaping the architecture around the firm's products. Proponents of LSI believe that the fears of critics are either unfounded or can be addressed by proper government oversight.

This report examines two case studies of LSIs, the Army's Future Combat Systems (FCS) and the Coast Guard's Integrated Deepwater System Project (Deepwater), to illustrate the challenges and benefits of using LSI by the federal government. Both programs have faced significant development challenges, especially in adapting to new requirements arising from post-9/11 legislation.

The Integrated Deepwater System Program is the Coast Guard's effort to completely modernize its entire service. The program has faced many challenges: an increase in required capabilities, acceleration of the program, and a natural disaster. Deepwater has experienced significant cost increases and schedule slippages that have led to the cancellation of several components. Due to these problems, the Coast Guard has taken

over the role of LSI, although the Coast Guard still relies upon the original LSI for support of its program management.

The Future Combat Systems, an Army brigade-modernization program, has also experienced cost growth and schedule problems. In this instance, initial development problems were compounded by an acceleration of the delivery schedule and the need to deliver incremental improvements to soldiers in the field that were not previously planned. Although the program has experienced some challenges, these are, in general, not attributable to the use of a LSI.

These case studies have produced three key “lessons learned.” First, although SoS integration is widely acknowledged as necessary to pursue SoS development, the presence of a LSI is not a cure-all. The military, lawmakers and industry must limit development programs based upon immature technologies in order to avoid these development problems. Second, while the government retained final authority rule over all important decisions, the Army and Coast Guard have been criticized for not exercising effective oversight of the LSI. Third, as presented by the FCS case study, it is important for military and industry to establish key shared-interests early in the development process. The benefit of establishing key shared-interests should be built upon, however, with the consideration of resource constraints.

The authors of the report arrived at the following findings:

1. The military is committed to SoS development.
2. SoS engineering and integration is a complex undertaking.
3. SoS development and integration is still a maturing discipline.
4. Government does not currently have capability or capacity to perform SoSE.
5. LSI programs have experienced technical difficulty for a variety of reasons.
6. Despite retaining final decision authority, the government has not consistently provided effective oversight of private LSIs.

7. The greatest concern regarding the use of LSI is the government's delegation of "inherently governmental functions."
8. A potential conflict-of-interest exists for private LSIs.
9. Unified leadership of the SoS integration affords the best chance of successful completion.

The authors of this report arrived at several conclusions:

1. The government should continue development of SoS programs that, if developed correctly, offer the potential for better value—more capability at equal or lower cost—to the military, than do individual procurements.
2. The government must effectively partner with the private sector to adequately perform the LSI function.
 - a. The DoD must provide better oversight and write contracts that are more clearly defined.
 - b. The DoD should accelerate its efforts to recruit, hire, and retain the required human capital required for program oversight (and, when required, program management) for the challenging SoSs acquisitions.
 - c. The government should enforce hardware and software exclusion provisions for system-of-system integration contracts.
3. Congress should modify the prohibition on the use of LSIs to permit either small-scale limited programs for LSIs (or large-scale programs for LSIs who are willing to take hardware and software exclusions), to examine and evaluate strategies to fully leverage private sector capacity, while ensuring adequate government oversight and avoiding conflict-of-interest concerns.

I. Introduction

Lead system integration is a strategy currently utilized by the Department of Defense (DoD) when pursuing large System-of-System (SoS) acquisition programs. A SoS acquisition program involves the purposeful integration of individual weapon systems, along with other task-oriented assets, yielding a capability greater than that of the constituent parts. Although a SoS acquisition program may involve the design and integration of a new set of weapons, it will more typically integrate new weapons platforms with legacy systems. SoS acquisition provides the DoD with the complete range of abilities it seeks in its next generation of fighting units. Instead of the acquisition of systems, platform-by-platform, the DoD can modernize a mission capability with a single, fully-integrated SoS development.

The DoD has been emphasizing defense acquisition reforms in response to the changing challenges and opportunities that have arisen since the end of the Cold War. Challenges to the military included a shrinking budget, an aging acquisition workforce that lacks cutting-edge technical expertise, and consolidation of the defense industry. Opportunities included advances in communications, robotics, and computing technologies. Finally, a broadening of the military's operational requirements, a byproduct of the post-9/11 security environment, further exacerbated the need to fill capability gaps quickly.

The DoD implemented new strategies to replace, augment, and integrate a large number of legacy weapons with highly capable future systems. One of these was SoS development: the simultaneous development of multiple weapons and platforms, purposefully integrated to yield certain force capabilities only attainable through high levels of integration and interoperability.

Believing that it did not have the organic technical and managerial capability to oversee such monumental development tasks, DoD employed private Lead System Integrators (LSIs) to oversee the SoS programs. LSIs are granted greater authority over a development program than traditional development program prime contractors. Depending on the structure of the contract, this authority may include requirements

generation, technologic development, source selection and other administrative duties. The DoD has utilized private sector firms as LSIs because the DoD believes the defense industry is best equipped to manage a “best-of-industry” development effort. Although the government could perform the functions of SoS integration in a future program (with contractor support), the government does not currently have the capacity to oversee a SoS program on its own. The current use of LSIs, principally large defense contractors, to fulfill the SoS integration has received heavy criticism for its apparent delegation of inherently-governmental authority to the private sector and the increased potential for conflicts-of-interest in “make or buy” decisions. As a result, in 2007, Congress passed the National Defense Authorization Act of Fiscal Year 2008 that prohibits the awarding of new LSIs effective October 1, 2010 (Congress 2008). The SoS integration function, however, remains important as long as the military wishes to pursue SoS developments.

II. Background: The Need for Large Scale Integration

Since the end of the Cold War, the Department of Defense (DoD) has prepared for war within the context of a rapidly-changing national security environment. Furthermore, coincident with the information revolution, visionary military leaders saw the potential for a Revolution in Military Affairs (RMA)—a fundamentally new way to wage war, taking full advantage of modern technologies. The military eventually developed and adopted the doctrine of Net-Centric Warfare (NCW) as the future fighting blueprint that would catapult the DoD into the 21st century. The need to implement NCW quickly created the incentive for senior leaders to push for a military transformation, which would require a new level of integration of individual systems and platforms, creating a host of interdependencies.

In an effort to address the greater level of integration that NCW required, an innovative acquisition strategy emerged: System-of-Systems (SoS) development. This new strategy views the constellation of military assets in an integrated and coherent way—as a complete, interconnected system. Military planners believed that SoS development would allow for the concurrent acquisition of a number of complex programs that would function collectively in the NCW environment.

The large scale and scope of the SoS development task requires an entity to orchestrate and perform the complex integration function. Contractors that perform the role of integrator for a SoS program have come to be known as the “Lead System Integrator” (LSI). Contracting with a LSI presented two anticipated benefits. First, LSIs offered the opportunity to optimize a SoS at the overall system, as opposed to the optimization of individual weapon systems that potentially sub-optimizes the system-level capability. Second, LSIs could reduce the cost of SoS integration by purposely planning for integration from the start of development as opposed to the costly integration of independently developed systems. Also, each “node” of the SoS need not be optimized on its own (vs. the overall system), so the individual elements could be lower in cost.

Revolution in Military Affairs

Following the end of the Cold War, the DoD undertook extensive analysis to determine how best the military should respond to the new set of circumstances. In 1999, the then-Secretary of Defense William S. Cohen advocated the previously-defined concept of a Revolution in Military Affairs (RMA). As defined by Cohen, a RMA “occurs when a nation’s military seizes an opportunity to transform its strategy, military doctrine, training, education, organization, equipment, operations, and tactics to achieve decisive military results in fundamentally new ways” (GAO 2004b). A RMA represents a dramatic change in warfare that alters the way war is fought thereafter, such as the use of blitzkrieg tactics by the Nazi Wehrmacht in 1939. Cohen believed that the U.S. had the opportunity to lead a similar radical change at the start of the 21st century, in large part due to the information revolution of the 1980s-1990s.

The RMA put forth by Cohen centered around five components:

1. Expanded use of smart munitions. Smart munitions will allow military forces to strike enemy targets with great precision at considerable distances.
2. Increased use of stealth technology. Stealth technology will enable military assets to penetrate an enemy’s defense with impunity.
3. Implementation of advanced robotics and computer technologies. Adoption of these technologies will facilitate the emergence of unmanned military systems that will ultimately provide relatively low-cost assets to replace humans in high-risk situations.
4. The ability to rapidly collect, synthesize and distribute information across a joint battle network. An information network will increase the effectiveness of joint force integration, presenting a more complete

battlefield situation to commanders at all echelons—effectively reducing the “fog-of-war.”¹

5. **Satellite Communications.** The distributed components (sensors and shooters) depend on unrestricted global telecommunications (which can realistically only be provided by satellites); the RMA will require the tactical and operational exploitation of space (Kosiak 2007).

The core tenet of the proposed RMA was that, in the next century, information will be a critical enabler for all battlefield operations. A secure and instantaneous information network will systemically synthesize the knowledge of all military forces into a cohesive understanding of the battlefield. This communications network will allow units to act with an unprecedented degree of exactness and cohesiveness. In order to fully implement the RMA concepts, the U.S. military will require a new battlefield strategy for the start of the 21st century.

Net-Centric Warfare

By 2001, the DoD was transitioning towards the military doctrine of Net-centric warfare (NCW) (Department of Defense 2001). The military felt NCW to be the best course of action to leverage the advantage of information integration to fight more effectively in the future. At its core, this warfighting strategy postulates that “information superiority, not military mass, [is] the key to military success. Overwhelming force would be less useful or effective than decisive force applied quickly and precisely” (Blaker 2006). NCW doctrine, alternatively known as Net-Centric Operations, asserts that the current way of fighting is slow and inefficient because the focus on eliminating the physical presence of enemies results in a war of attrition. In contrast, NCW doctrine seeks to increase military effectiveness by emphasizing speed and agility and using concurrent targeting to rapidly disrupt and disorient the enemies’ ability, and desire, to fight.

¹ A term used to describe the level of ambiguity in situational awareness experienced by participants in military operations.

NCW is characterized by complete battlefield awareness, self-synchronization of forces, and the overwhelming and precise application of force. By enabling each element of the military force to detect and distribute information, that force can achieve complete battlefield awareness. Gathering and synthesizing this currently dispersed information would significantly reduce warfare uncertainty arising from the “fog of war” and provide several benefits. First, individual assets would use this information to more quickly assess and respond to situations, shortening the often time-consuming coordination and decision. Second, complete battlefield awareness, along with advances in precision munitions, would also allow for far more accurate fire placement and verification of accuracy. Third, increased information flow would allow units to act as a cohesive whole even when assets are not geographically concentrated. Altogether, “owing to their information superiority, the armed forces will put into practice the principle of the massing of results, not the massing of forces” (Gorbachev 2006). A theoretical NCW interaction is presented in Figure 1.

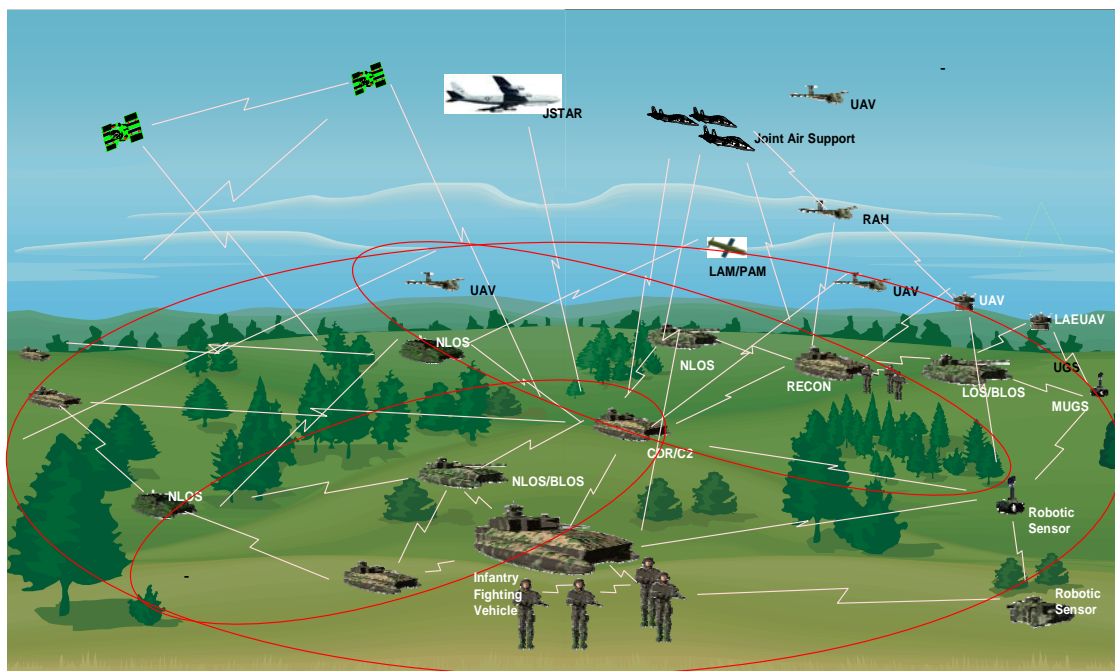


Figure 1: Theoretical NCW interaction (source: www.dtic.mil/ndia/2004test/thurs/thompson.ppt)

In order to implement the NCW doctrine, the DoD would need to modify or replace many aging military weapons, near simultaneously. As a result, a new large-scale development strategy was formulated, the objective of which was the planned and purposeful integration of new and legacy military weapons and systems (i.e., SoS development).

A System-of-Systems Perspective

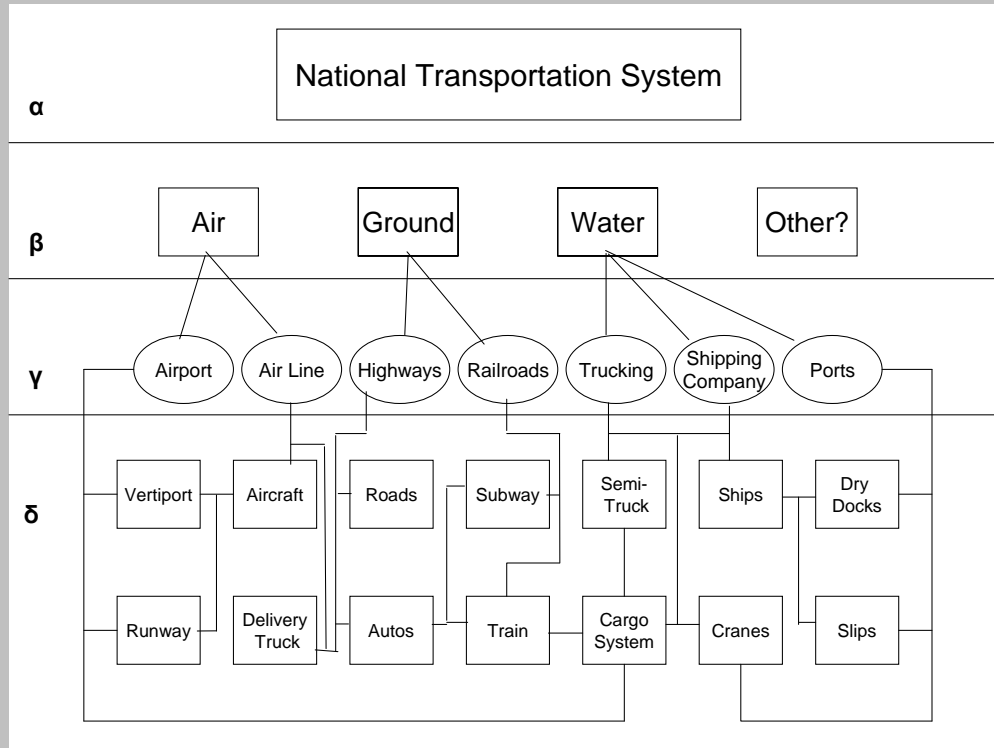
The DoD's Defense Acquisition Guide defines a SoS as "a set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities" (Defense Acquisition University 2006). Most SoS definitions include five key characteristics: operational independence, managerial independence, geographical distribution, emergent behavior, and evolutionary development (Sage 2001). Operational independence enables individual components to function autonomously, outside of the SoS if necessary. Managerial independence ensures that units have the knowledge to act individually in an effective manner at all times. Geographic distribution permits units to function in a coordinated manner even while geographically dispersed. Emergent behavior describes certain synergistic and new capabilities not inherent to the component systems individually, but that are attainable with their integration—wherein the total is greater than the sum of its parts. Finally, evolutionary development acknowledges the potential growth in the capability of the system over time due to modification of current assets or the addition of new weapons. These traits differentiate a SoS development from either an individual asset or a mere collection of platforms.

Extensive planning is required to field a SoS platform. The Defense Acquisition Guide describes System of Systems engineering (SoSE) as the process of "planning, analyzing, organizing, and integrating the capabilities of a mix of existing and new systems into a system of systems capability greater than the sum of the capabilities of the constituent parts" (Defense Acquisition University 2006). The express purpose of SoSE is to integrate the attributes of individual weapons and systems to produce a single system with a capability only attainable through comprehensive interoperability. If undertaken during development, SoSE provides the DoD with the unique ability to simultaneously

field the full range of capabilities that it seeks in its next generation of military units. SoSE requires a high level of integration to produce its desired outcomes. As a result, it will work best if one entity manages and coordinates the complex, large-scale program. Responsibilities include directing the systems engineering, architecture development and element selection—all within an affordability constraint.

A Civilian System-of-Systems: The National Transportation System

An example of a civilian SoS is the national transportation system (NTS). (In the depiction, Greek letters refer to different levels of systems. *Delta* refers to the lowest level while *alpha* refers to the entire SoS.) A number of interconnected systems comprise the NTS, including air, ground and water transportation. Each of the subsystems, however, may be thought of as a SoS in and of itself. For example, ground transportation is comprised of highways and railroads. Interdependencies not apparent at the highest level may be seen more clearly at the lower levels. Overall, although each system is able to operate independently, the NTS relies upon the systems working together as a single system to provide effective transportation around the nation.



(DeLaurentis 2004)

SoS in the DoD

The DoD's capabilities are currently comprised of a number of implicit SoSs. As described by the Office of the Deputy Under Secretary of Defense (Acquisition and Technology) in 2007, "most military systems today are part of an SoS whether or not explicitly recognized" (Office of the Under Secretary of Defense (AT&L) 2007). Imbedded in this explanation is an understanding that military systems and units do not

function in isolation, but instead, function as cogs in the machine of an integrated force. For example, a Navy carrier battle-group may be viewed as a SoS since it is comprised of an aircraft carrier, its complement of aircraft, and the other supporting ships.² Although the ships and individual planes may function independent of one another, the battle-group will not be effective without synchronized action. This is still a limited view, though, since the battle group can be viewed as one part of a larger SoS. At a minimum, the battle group needs supporting information and intelligence from another network of systems (satellites, local UAVs, surveillance aircraft) to attain maximum functionality. One can easily envision several other distributed sensors providing information to distributed shooter systems. To attain the greater integration and synergy required to successfully employ the concept of NCW, the DoD needs to use the SoSs perspective and appropriate SoSE techniques.

Although a SoS provides the DoD with the opportunity to attain capabilities that the DoD is unable to achieve through the procurement of individual systems, the SoS process also poses new risks. Every system within the SoS has a specific role and purpose to perform in order for the entire entity to operate effectively. From an engineering standpoint, these interactions and interdependencies must be taken into account. For this reason, the DoD's principal development concern must shift from the platform-centric perspective (optimize at the platform level) to the purposeful integration of platforms into required SoSs (optimize at the overall SoS level). If a SoS view is not utilized, difficulties in one subsystem could have deleterious effects upon the entire SoS.

SoSE vs. Traditional engineering

SoSE and traditional engineering differ in several significant ways. The primary difference between traditional engineering and SoSE is epitomized by the goal each tries to achieve. The former sets out to optimize the performance of a single system, given specific end-requirements. Once the system has reached the extent of its usefulness, a

² Some argue that all systems comprised of systems are SoS. Within this framework, an aircraft is viewed as a SoS, as it is comprised of a number of a number of systems and subsystems (e.g., flight control and weapons targeting systems) that must work together to correctly perform its required functions. Since its individual components are incapable of operational independence however, the plane would not be considered a SoS.

new entity will be developed to replace the current one. The latter engineering method pursues a different end-goal: to develop a certain capability, attainable through the integration of individual assets into a SoS. Although some assets of the SoS may be interchangeable, the overall capability is not.

Whereas traditional engineering places emphasis on individual systems, by designing around a capability, SoSE puts utmost importance upon the collective ability of the system. Due to this shift in emphasis, SoSE has two unique challenges. First, a SoS has a theoretically infinite lifespan as SoS are “enduring even though the individual systems that comprise them have finite lifetimes” (Kaplan 2006a). A useful capability, such as an integrated communications network, can be maintained indefinitely through a continuous process to update old systems through new acquisitions. Second, a SoS has unbounded development requirements. As the lifetime of a system may be infinite, and the program evolves over time, end requirements may not be fixed beyond a single design iteration.

Other differences exist between SoSE and traditional engineering. These dissimilarities draw out the distinction between the two engineering views. Many of these differences are discussed below and summarized in Figure 2.

Design requirements

Traditional engineering relies on designing around a “well-bounded system ... predicated on having well-defined, precise, and stable requirements” (Stevens 2004). Given exact performance standards, the engineers design a system to meet the desired specifications. As the engineers have the knowledge of the desired endpoint, the challenge arises from making appropriate technical tradeoffs to accomplish the goal.

In contrast to traditional engineering, SoSE does not have a specific endpoint. Lacking an endpoint, engineers are unable to optimize the performance capabilities of a single system. In effect, an unbounded set of development requirements exists. The flexibility of SoSE allows the individual systems and the system-of-systems to adapt to the challenges of the future as they arise. In this way, SoSE avoids the design problem of

traditional engineering: designing for the wrong problem or designing around the wrong set of system parameters.

	Traditional Engineering	SoSE
Goal	Optimized system	Capability
Lifetime	Specific design lifetime	Indefinite lifetime
Design Requirements	Bounded	Unbounded
Size	Single system	Multiple systems
Governance	One dominant influence	Multiple, overlapping spheres of influence
Independent developments	Rare	Common

Figure 2: Differences between traditional and SoSE

Size

The large size of a SoS complicates its engineering task. SoSE must pull together numerous projects and integrate them into a cohesive whole. More likely than not systems were, are, or will be developed independently. Traditional engineering, focusing on a single entity, does not have this uncertainty present in the design phase. On the other hand, SoSE is able to leverage the unique advantages of each system in the SoS to produce emergent behavior, which traditional engineering has difficulty attaining.

Governance

Since a SoSE program can span multiple organizations, a variety of authorities may be in a position to influence the decision-making process. The consistent battle for influence continues throughout the lifetime of the SoS, as its abilities evolve over time. Traditional engineering projects tend to have one overall concern: reducing the chance of conflicting objectives.

Independent innovation

Independent innovation is less likely to occur in the development of a single system that has clearly defined requirements. With a predetermined set of requirements, traditional engineering extensively plans development to bridge the gap of knowledge between what is achievable today and the project's end result.

Independent innovation is much more likely in the development of multiple systems with unbounded requirements. As the final endpoint is not known, SoSE fosters innovation that will derive new solutions across the entire SoS. The development of multiple systems independently provides more opportunities for independent development at the individual system level.

Why pursue SoS development?

SoS development is the development and procurement of several individual systems or assets concurrently that will operate optimally as one system. SoS development provides the DoD with the unique ability to integrate and field the full range of assets (new and legacy) to provide required military capabilities. Due to the size and cost of such an undertaking, the DoD has only undertaken a small number of SoS development programs. Most of the DoD's SoS efforts consist of synthesizing the abilities of existing systems to address capability needs.

Historically, the DoD's acquisition programs have tended to face an assortment of problems: delayed schedules, increased budgets and inadequate asset capabilities when units are finally fielded. Individual acquisition, in particular, poses two glaring problems for the DoD:

1. When integration of systems occurs after production, the effort tends to be costly and time consuming, without offering a guarantee of effective performance. Integrating communications systems after development, for instance, often results in capabilities not as effective or secure. All too often, "today's systems ... provide only a loosely coupled conglomeration. They either do not pass data at all, or only partially pass data between components." (United States Air Force Scientific Advisory Board 2005). Integration of extant communications systems requires significant resources, while reducing readiness levels in the short term. More importantly, however, these efforts often incur costs without significantly increasing performance.

2. Piecemeal acquisition efforts undermine systematic long-term military planning. Under the current development system, the military does not have the flexibility or foresight to properly manage development tradeoffs. Although individual systems are optimized, interaction between platforms often remains sub-optimal. Since legacy systems were not designed for synchronized combat, the military still struggles to field a truly cohesive force. Without prior planning, the military is more likely to end up with a collection of individually optimized systems than a SoS.
3. In contrast to the difficulties faced by traditional engineering, SoSE overcomes these two problems. An integrated SoS offers the advantage of equal or better performance at lower cost. Instead of wasting resources developing optimal elements that do not (or at least, do not cost effectively) contribute to the performance of the SoS as a whole. The capacity of the SoS is enhanced by purposeful pursuit of emergent and synergistic behavior, which may reduce the capabilities that individual elements need to attain for the SoS as a whole to be effective. SoSE offers additional advantages, such as enhanced opportunity for compatible components used within the system, as exemplified by Future Combat Systems.

SoSE allows for development tradeoffs that traditional engineering cannot take into account. Tradeoffs can occur among the assets that comprise a given SoS at a given point in time or can occur across the lifespan of the SoS. SoSE also enhances the value of the end product by purposely synthesizing the attributes of a group of units into something that is greater than the sum of the individual parts. Altogether, purposefully designing systems to interoperate would facilitate a higher flow of information between members of the military, enabling swift implementation of NCW (Kaplan 2006b).

III. Challenges for DoD

The DoD has faced, and continues to face, many new challenges in the 21st century. Many of these will contribute to an evermore challenging acquisition environment; these factors are summarized below. At the same time, SoS development has some unique development challenges; these are also addressed below.

DoD's Challenging Acquisition Environment

The DoD will face an extremely challenging acquisition environment in the 21st century. While military forces continue to confront a broad spectrum of operational challenges, they will continue to transform and adopt the NCW doctrine in the face of shrinking budgetary resources, an insufficient acquisition workforce, and consolidation of the defense industry.

Increased Military Requirements

Military requirements have increased significantly since the start of the 21st century for three reasons. First, there exists a broad spectrum of potential scenarios from terrorism through expeditionary operations, through regional conflicts, and through potential future peer competitors to nuclear deterrence. Second, the military's adoption of NCW has propelled the military towards SoS development. Third, post-9/11 requirements have significantly increased the military's deployment and operations tempo.

Budget Constraints

The nation's future budgetary situation will constrain future DoD funding. Mandatory federal budget expenditures—particularly Social Security, Medicare and Medicaid—will rise significantly, reducing resources available for defense spending. At the same time, the military's costs are expected to rise significantly, stemming from current conflicts abroad. Overall, the DoD's budget decline will most adversely affect research and acquisition spending.

Acquisition Workforce

The DoD acquisition workforce has not maintained the capacity or capability to effectively pursue even independent weapons acquisition. The acquisition workforce has three intertwined problems. First, the sharp reduction in acquisition personnel since the Cold War (approximately 60% between fiscal years 1990 and 2006) has left insufficient bodies to fill all positions required for large-scale development programs. These reductions were made without a strategic vision of what would be needed in the future and relied on voluntary turnover, retirements, freezes on hiring authority, and mandated Congressional cuts. Moreover, recent increases in military expenditures were not matched by an increase in acquisition personnel. Second, close to 70% of the DoD's current acquisition workforce are "baby boomers" and will be eligible to retire in the next decade (Gansler 2008). Third, and closely related to the previous issues, the acquisition workforce currently lacks many of the cutting-edge technical capabilities needed for complex system-of-systems development tasks.

Consolidation of the defense industry

The DoD has always relied on the private sector to help develop advanced new weapons for the military. By the 21st century, private industry performed most acquisition functions while the DoD's organic capacity diminished. Following the DoD's post-Cold War budget cuts, the DoD strongly encouraged the defense industry to consolidate, in some cases even reimbursing firms for the costs of merger and acquisition activities. Consolidation has reduced the number of major defense contractors available to bid for a contract; during the current period of high defense spending, the DoD is reliant upon a defense industry that now boasts only a handful of firms. Vertical integration by these remaining firms has also eliminated the few large systems engineering firms that once helped the government objectively (with a hardware exclusion) manage the major hardware producing firms.

Specific SoS Development Challenges

In addition to the stressful acquisition environment that all DoD acquisition programs will continue to face, SoS development programs have several additional managerial

challenges. Areas emphasized by the 2006 Defense Acquisition Guide include larger development scale, more intricate integration efforts, engineering in an environment where end requirements will change, concurrent engineering and rigorous interface standardization (Defense Acquisition University 2006). These concerns are compounded by the early use of SoSE, which lacks generally accepted practices or even a widely agreed to definition. Finally, the process is undermined as both “current and proposed acquisition systems insufficiently facilitate SoS development” (Moran 2008) through extensive regulation. Specific SoS development challenges include an inconsistent understanding of SoSE within the acquisition workforce, the interconnected nature of SoS development, the lack of a codified method to approach SoSE, adaptability requirements, the scale of SoS developments, and budget instability.

Inconsistent Understanding of “SoSE”

The biggest hindrance to effective SoSE is the acquisition community’s lack of understanding regarding the definition of the term SoSE and its implications. Currently, multiple definitions of SoS and SoSE exist in the literature, with little consensus among the variants (Sage 2001; Jamshidi 2005). Widespread confusion exists within the acquisition workforce, as the results from a recent survey undertaken by the United States Air Force Scientific Advisory Board attest: “only about 5% [of the acquisition workforce] had the desirable perspective of SoS as collaborative systems that will be brought together in the field, recognizing it as a ‘pick-up’ game that will always be a pick-up game as needs will change” (United States Air Force Scientific Advisory Board 2005). As SoSE is focused on a system capability that is enduring, while mission and performance requirements change, the SoS will always require new systems to replace expiring assets. Without an appropriate and consistent understanding of SoSE throughout DoD acquisition, the process is unlikely to be implemented effectively.

Interconnected Nature of SoS Development

The biggest misconception of SoSE is that engineering for SoS is simply the application of traditional engineering techniques on a larger scale. In the traditional engineering framework, the goal of a development project is to optimize the performance of a

particular asset. If there are multiple assets within the overall program, each asset should be individually optimized to derive the maximal individual performance. In this framework, it is believed that the whole is equal to the sum of its parts. Therefore, if one optimizes the performance of the components that make up the entire program, one increases the performance of the whole.

The problem with this narrow engineering viewpoint, however, is that when “effectively segregated into discrete communities, stakeholders act without appreciating consequences in a broader organizational context. As a result, decisions intended to alleviate one problem often carry unintended consequences that aggravate others” (Moran 2008). In other words, a narrow development focus fails to take into account how changes in one component of the whole may affect the performance or requirements of other components of the entire system. If one system relies upon a second system having a minimum threshold capability that is not realized, the first may have to be modified. Conversely, optimizing the performance of an individual platform may not necessarily increase the performance of the SoS, and may, in some cases, degrade its overall performance. Due to the size and interconnected nature of SoS, one problem may have ripple effects.

SoSE focuses on acquiring a capability, within an affordability constraint, and actively manages the capabilities of the systems as a whole, instead of assembling and integrating a collection of independently developed systems. In this way, SoSE nurtures emergent behaviors while allowing for effective tradeoff of abilities and resources throughout the entire SoS.

These advantages are best realized when proper knowledge-based acquisition guidelines are utilized. Great care must be taken to ensure the feasibility of the program at the outset and to properly weigh the tradeoffs of a single system within the context of the whole SoS. Without proper planning, any problem, such as the delayed development of an individual technology, can have deleterious ripple effects throughout the entire SoS program.

SoSE Practices Still Maturing

Another problem that SoSE faces, at least initially, is the lack of a comprehensive guide to this new form of engineering. As noted by one study, “investigation of the state of maturity for engineering a system-of-systems revealed that there was little in terms of codified practice or discipline that could be adapted for use within the DoD” (United States Air Force Scientific Advisory Board 2005). Although examples of SoSE exist in the commercial and military spheres, SoSE practices are still maturing. As a result, SoS engineers must, to some degree, still learn by doing.

Adaptability

A core characteristic of good SoS design is the ability to change and adapt to future concerns, even as such concerns are not known at the time of development. “Ideally the SoS design/architecture will persist over multiple increments of SoS development, allowing for change in some areas while providing stability in others” (Office of the Under Secretary of Defense (AT&L) 2007). The architecture must have enough stability to provide the foundation for future changes, while being flexible enough to avoid rapid obsolescence. Such development concerns, however, may be difficult to foresee, especially in light of today’s rapidly changing technology.

Interface Standards

The use of commercial standards or open source interface standards is one of the most important features the SoS development process requires to facilitate cross-generational adaptability. The use of proprietary standards in most existent military units precludes easy and seamless plug-and-play compatibility between systems and subsystems. Moreover, the design of a system to include proprietary standards limits the ability of the DoD to compete certain components while allowing the firm with the proprietary rights to charge monopoly fees.

Information Assurance

A particular concern of any SoS is information assurance. As so much of the capability of a SoS relies upon safe and uninterrupted communications, any breach or prolonged disruption could significantly compromise the system. A military SoS must provide adequate security while still allowing a seamless transmission of information between military units.

Scale of SoS development program

The large scale of a SoS acquisition program complicates development, by necessitating the simultaneous development of a large number of assets, each which would have traditionally been viewed as a major acquisition program. Most SoSE programs principally require the cobbling of present assets into a SoS. Development of a SoS program, however, requires the acquisition and integration of all assets either at the same time or in a time-phased deployment. The sheer size of the program could prove difficult to synchronize, while requiring significant managerial and engineering capability and capacity.

Budget Instability

Unstable budgets undermine the efficiency of traditional engineering programs by not allocating an effective level of resources to projects and not allowing program managers to plan for the future. Whereas traditional engineering projects may be hindered by unstable budgets, SoS projects will lose their flexibility to rapidly adapt to new opportunities or threats. The situation is made worse as “the inherent characteristics of a SoS will likely produce less stable budgets. Division of programs into individual budget line items tends to emphasize unitary goals, as opposed to the pluralistic goals of an SoS” (Moran 2008). Congress’ propensity to legislate exact specifications or restrictions on SoS programs may further undermine the development’s flexibility.

IV. Lead System Integrator

In order to properly manage the risks of a SoS development, a responsible agent is needed to fulfill the role of coordinator and manager of the complex effort. This agent must provide commonality across multiple weapons platforms and ensure a common vision for the program. One strategy to accomplish these goals is for the government to contract a Lead System Integrator. There is no exact definition of a Lead System Integrator or the functions an LSI undertakes, which complicates discussion of the issue.

The first program that appears to have pursued a SoS development using a LSI (although that term was not used) was the Coast Guard's Deepwater modernization project in 2001. That contractor was responsible for "ensuring that each ship, aircraft, or other equipment is delivered on time and in accordance with agreed to prices ... [and] in compliance with the Coast Guard's system performance specifications" (GAO 2001). The first specific use of the term LSI was used by the Army's Future Combat Systems (FCS) in 2003. The responsibilities of the LSI were defined as "focuse[d] on system engineering, system integration, system planning and control" (Gully 2003). This lack of a clear definition for LSI leads to some confusion between the government and industry regarding appropriate responsibilities in this new partnership.

LSI Functions

For the purposes of this paper, LSI is defined as it has been used in practice: a government-contracted entity to design, integrate and manage the development of a large, and complex SoS program. In this role, the LSI must oversee the technological maturity, subsystem development and make decisions regarding tradeoffs within the context of the system-of-systems (on performance and costs among the various SoS and individual system elements). In addition, however, the LSIs have been given broader, government-like authority that includes development of individual system requirements, contracting for their development and procurement, and coordination of development schedule and effort. A LSI may have additional responsibilities including technology development,

testing, validation, procurement, and sustainability. The degree of authority and responsibility given to an LSI, however, depends upon the program in question.

It was believed that LSIs require greater authority than a traditional prime contractor because SoS development is more complex than traditional development programs. An LSI, intimate with available resources and technology maturity, would be in the best position to determine what requirements are appropriate within a development cycle to maximize the overall capability of the SoS. The LSI could take a holistic view of the SoS and determine where and when to place resources. LSIs require management of supplier firms to minimize bottlenecks in the development process. LSIs always provide system-wide administration, centralizing information for analysis, disseminating information as required and managing resources.

Why the government currently has difficulty performing the system-of-systems integration function

The DoD, as well as other government departments, currently lacks the culture, capability and capacity to perform LSI. Culturally, SoS development requires great collaboration across a variety of disciplines and departments. Historically, the DoD has faced challenges developing stand-alone systems, let alone integrating several research and development initiatives. In terms of capability, the DoD currently lacks the number of technically skilled personnel required to concurrently manage the development and integration of multiple weapons systems—a SoS. The DoD tends to lack capability in areas in which it requires skills most, such as systems and software engineering and cost/performance tradeoffs. In the case of the Coast Guard, for example, the government had trouble filling the relatively small number of acquisition positions required for its oversight of the Deepwater program when a Lockheed Martin-Northrop Grumman team was the LSI. In order to assume the entire SoS integration role, the government would need to invest significant resources to recruit, hire and retain the necessary workforce. As a result, the alternative LSI arrangements allow the LSI to become the enabling partner of the government in the development of a new SoS weapons program that the DoD would be unable to pursue on its own.

Inherently Governmental Functions

Critics were concerned that by awarding LSI contracts the government would delegate some inherently governmental-like authorities without being able to provide adequate oversight of the LSI. As with the definition of LSI, however, the definition of “inherently governmental functions” leaves room for interpretation.

The Office of Federal Procurement Policy defines the term as a task “so intimately related to the public interest as to mandate performance by Government employees. These functions include those activities that require either the exercise of discretion in applying Government authority or the making of value judgments in making decisions for the Government. Governmental functions normally fall into two categories: (1) the act of governing, i.e., the discretionary exercise of Government authority, and (2) monetary transactions and entitlements” (Office of Federal Procurement Policy 1992). Despite the vague definition, several tasks are generally assumed to be inherently governmental including structuring and evaluating contracts, evaluation of offers, award, termination of contracts and requirements determination and regulation (Lamm 2007). Other tasks traditionally performed by the government—such as market research, weapons design, procurement functions, and maintenance—have also been contracted out.

Proponents of LSIs believed that the fears of critics were either unfounded or could be addressed by proper government oversight. When the government signs a contract to delegate some of its authority to a LSI, it continues to maintain the responsibility for the success of the program as well as its responsibility to manage the LSI. The government needs to ensure that the contractor does not abuse its position of power and that the interests of the government are upheld.

Two types of LSI Contracts

Due to mounting concerns regarding the use of LSI contracts, Congress included an official definition for the term in the National Defense Authorization Act for Fiscal Year 2006 (Public law 109-163-Jan. 6, 2006). In this definition, Congress strictly defined two possible types of LSI contracts:

- (1) The term “lead system integrator” includes lead system integrators with system responsibility and lead system integrators without system responsibility.
- (2) The term “lead system integrator with system responsibility” means a prime contractor for the development or production of a major system if the prime contractor is not expected at the time of award, as determined by the Secretary of Defense for purposes of this section, to perform a substantial portion of the work on the system and the major subsystems.
- (3) The term “lead system integrator without system responsibility” means a contractor under a contract for the procurement of services whose primary purpose is to perform acquisition functions closely associated with inherently governmental functions with regard to the development or production of a major system. (Congress 2006)

The vagueness of this definition leaves open the possibility of multiple interpretations. This report interprets the definition of both types of contracts within the framework of a SoS development program. A LSI with system responsibility is a prime contractor that is primarily responsible for developing or producing a system but will subcontract most of the actual work. The LSI is responsible for the delivery of the completed, integrated, system to the government. A LSI without system responsibility is a prime contractor that is delegated government-like authority to perform what are typically considered inherently governmental functions. These would include tasks such setting requirements and contracting for the development and production.

Opportunities and Challenges of pursuing Private LSI

Contracting with a prime contractor to perform as a LSI offered some immediate apparent benefits, since in contrast to the government, these firms generally have greater capacity and capability (i.e., number of skilled individuals required, as well as more personnel flexibility), the pressure of competition, and superior more immediate access to innovating technologies. Due to standard private business practices, firms are able to more quickly scale and tailor their labor force to the level required for a program. Firms can also easily subcontract jobs in a timely manner to those companies most qualified to succeed at the job. Private firms have greater flexibility to change budget flows as more knowledge becomes available or the priorities of development change. Based on salary flexibilities, private sector firms are able to attract and retain the best human and technical expertise in much greater numbers than is the government. Finally, as a result

of the information revolution, most of the critical innovations relevant to systems integration come from the commercial sector, not the government, and, in most cases, private firms can access such innovations more easily. As a result, a private LSI provides the government with the most flexible and adaptable partner in SoS acquisition.

Several realities make LSI attractive:

- **SoS:** Attaining a more capable armed force will require leveraging the integrated capabilities of SoS.
- **Capability:** Private industry is better able than the government to pull together resources to develop a program as large and complex as a SoS development. The government does currently not have, nor is likely to reconstitute in the near term, the technical and managerial capacity to direct the development of a SoS development program.
- **Innovation:** Most technical innovation and development takes place within the private sector. The government does not have, nor is likely to reconstitute, the technical or managerial capability to direct the development of a SoS development program.
- **Flexibility:** Private industry has greater flexibility to adapt to changing conditions and requirements than does the government. Flexibility is imperative to a SoS development program, in which the implications for technology on one subsystem can dramatically affect other portions of the system.

V. LSI in practice

The government has used a private LSI for several programs since 2002. The two best known programs are the Coast Guard's Integrated Deepwater System Program (Deepwater) and the Army's Future Combat Systems (FCS). These programs represent the main modernization program of their respective service. Both programs are a long-term, multi-billion dollar investment that will dominate service budgets over the next 25 years. Both the Deepwater and FCS programs have contracted with large defense firms that will have responsibility for system components. The initial LSI for Deepwater was Integrated Coast Guard Systems, a joint venture of Lockheed Martin and Northrop Grumman. At present, the Coast Guard performs the system-of-systems integration function. The LSI for FCS is Boeing, which has subcontracted managerial responsibilities with Science Applications International Corporation (SAIC).

It should be noted, however, that both programs are SoS development programs, and will produce an integrated system principally by developing several new systems not previously fielded, but they will also integrate legacy platforms.

The Coast Guard's Integrated Deepwater System Project

The Coast Guard's Deepwater is a development program aimed at modernizing the entire Coast Guard fleet—projected to cost up to \$24 billion over a potential 25-year development period.



When initially proposed, Deepwater was to develop 15 major classes of sea and air vehicles to replace all current Coast Guard assets and provide a new command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) system. The original contract stipulated delivery of 91 new cutters, 124 smaller surface

craft and 244 new or modernized manned and unmanned air vehicles. Deepwater, like FCS, advocates a net-centric warfare (NCW) doctrine. At the heart of the SoS is a complex information communications system connecting all assets that will act as a “force multiplier” in the protection of U.S. waterways. If completed as planned, the Coast Guard will represent the first service to fully adapt SoSE principals throughout its operational hierarchy. Figure 3 contains short descriptions of Deepwater assets along with their individual development status as of June 2008.

Background

By the early 1990s, the Coast Guard reported its fleet was becoming antiquated. The Coast Guard decided to pursue a system-of-systems approach because it would permit the “Deepwater project to be optimized (i.e., made cost effective) at the overall, system-of-systems level, rather than sub-optimized at the level of individual platforms and systems” (O’Rourke 2006). In 1998, the Coast Guard issued a Request for Proposal to three development teams for a complete fleet overhaul. The three systems integrators proposals were from Science Applications International Corporation, Litton/Avondale Industries, and Lockheed Martin Naval Electronics and Surveillance Systems (GAO 2001).

Current development status of Deepwater assets as of June 2008

Deepwater Assets		
Name of Asset	Description of Asset Capabilities	Status as of June 2008
National Security Cutter	Extended on-scene presence, long transits, and forward deployment worldwide	Capability development and demonstration
Fast Response Cutter	Multi-mission patrol boat with high readiness, speed, adaptability, and endurance	Capability development and demonstration
Offshore Patrol Cutter	Long distance transit, extended on-scene presence, operations with multiple aircraft and boats	Concept and technology development
Long-Range Interceptor	Deployable from FCS and OPC for vessel boarding, pursuit and interdiction, and search and rescue operations	Project Initiation
Short-Range Prosecutor	Deployable from FCS and OPC for law enforcement operations and perform search and rescue operations	Project Initiation
HC-144A Maritime Patrol Aircraft	Transportation and surveillance	Capability development and demonstration
HC-130J Long-Range Surveillance Aircraft	Surveillance and information coordination	Production and deployment
HH-65 Multimission Cutter Helicopter	Short-range recovery helicopter	Varies
HH-60 Medium Range Recovery Helicopter	Medium-range recovery helicopter	Varies
High Altitude Endurance Unmanned Air Vehicle	Large area surveillance	Production and deployment*
Vertical Unmanned Aerial Vehicle	Cutter-based asset to provide extended surveillance	Project identification

Figure 3: Description of Deepwater Assets (GAO 2008c), (GAO 2008a)*

Integrated Coast Guard Systems

In June 2001, Lockheed Martin and Northrop Grumman formed the joint venture Integrated Coast Guard Systems, LLC (ICGS) to pursue the Deepwater contract. This contract formalized the relationship for the two companies that had been informally pursuing the Deepwater development for three years. The two companies are equal

owners in the joint venture (Integrated Coast Guard Systems Deepwater 2002). The companies argued that the joint venture would enable them to yield a best-of-industry effort. Critics believed that the joint venture would not guarantee the anticipated best-of-industry effort, especially since competitive pressure would be reduced. Despite these concerns, the Coast Guard awarded ICGS the Deepwater contract in June of 2002.

Initial Contract

The initial Deepwater contract was for a 20-year, \$11 billion project. The contract included the possibility of extension to \$17 billion over a 30 year time period (Integrated Coast Guard Systems Deepwater 2002). ICGS was awarded the first five-year increment for the development. In order to allow competition, the contract leaves open the possibility of up to five more contract awards, for up to 60 months each. In contrast to most security and DoD procurement agreements, the Deepwater contract has performance-based requirements.

The Deepwater contract had several unique features. First, the Coast Guard selected a Lead Systems Integrator to develop the large SoS program. The Coast Guard justified this decision by stating that it lacked the inherent capability to perform the development management independently. The Coast Guard will remain integral to the Deepwater project and have final decision authority on all system-wide decisions. Second, the Deepwater contract allowed the LSI great flexibility to determine end outputs. The Coast Guard “has specified the outcomes it is seeking to achieve and has given the system integrator responsibility for identifying and delivering the assets needed to achieve these outcomes” (GAO 2004a). In contrast, a typical contract for an acquisition project stipulates strict technical requirements before program initiation. The current arrangement gives the LSI considerable authority to pursue the required objective. Third, the contract was structured as a performance-based agreement to hold the contractor accountable for its development decisions. The performance based agreement allowed the Coast Guard to “achieve measurable results in each of its primary mission areas ... [so that] the Deepwater contractor will ultimately be held responsible for delivering Coast Guard performance, not just specific assets” (U.S. Department of Homeland Security

2005). Fourth, the contract had a very complex structure. The contract is primarily an “Indefinite Delivery–Indefinite Quantity” agreement wherein the LSI has responsibility for fielding the entire SoS. As its name implies, the IDIQ contract stipulates that the Coast Guard may order any number of assets to be delivered; however, the Coast Guard has principally agreed to the delivery of the quantities stated above. Although the IDIQ agreement provides the Coast Guard with more flexibility to respond to issues as they arise, the contract also raises the unit cost of assets, since the LSI is unable to plan procurement of materials in advance. The contract also contains a number of subcontracts that utilize a number of different contract vehicles including cost-plus-award fee, cost-plus-incentive fee, firm-fixed-price, cost-plus-fixed-fee, as well as time and materials (Conrad 2006). Finally, the LSI’s profit is “dependent on performance through cost plus award fee and execution of individual Delivery Task Orders (DTOs). Incentives include award fee, award term, value engineering change proposals, and share-in-savings arrangements. In the event of budget fluctuations, Deepwater’s contract will function like other contracts” (U.S. Department of Homeland Security 2005). The complex nature of the contract made it difficult to understand the profit structure and how it would incentivize the LSI, although their intent was to keep development costs low while fulfilling performance requirements.

Program Restructuring

The Coast Guard awarded the Deepwater contract after the terrorist attacks of 9/11 but before post-9/11 legislation. Although the Coast Guard was aware that its mission profile would change significantly following legislation, it decided to proceed with the development of the program because the need to replace its antiquated ships could wait no longer. The subsequent legislation, which greatly expanded the Coast Guard’s operational mandate, necessitated a restructuring of the Deepwater program in July 2005. At the same time, the program’s budget was increased to \$24 billion and the development period was extended to 25 years to cover additional capabilities (Stephen L. Caldwell 2008).

Additionally, the Coast Guard's mission was significantly expanded from its traditional role to include many new homeland security commitments. In general, its new obligations fell into two categories: "those related to homeland security missions, such as port security, vessel escorts, security inspections, and defense readiness; and those related to non-homeland security missions, such as search and rescue, environmental protection, marine safety, and polar ice operations" (GAO 2008c). As a result of these changes, the Coast Guard made several changes to the Deepwater development project. These changes included an increase in Deepwater's development requirements, an acceleration of several assets' development schedules, and the need for a more capable stop-gap force during the development interim.

Deepwater challenges

The Deepwater program has encountered numerous development challenges, which have been compounded by the accelerated timetable and increased capabilities requirements in response to legislation after 9/11. In short, the rush to produce vessels on time has led to cost and quality-control problems. Two of the prominent issues with the Deepwater program have been the failed conversion of the 110-foot cutters to 123-foot cutters and the cancellation of the Fast Response Cutter (FRC).

110' to 123' conversion

To provide a stopgap capability to fulfill the Coast Guard's new homeland security mission, the expanded Deepwater program planned to extend the Coast Guard's fleet of 49 110-foot cutters to 123 feet. The Coast Guard deemed extension of these ships necessary to extend service life and accommodate new mission requirements. By September 2004, eight hulls had entered the conversion process, and four had already been delivered. In early September, the Coast Guard ordered one of these ships, the United States Coast Guard Cutter (USCGC) Matagorda, to proceed as quickly as possible out of the Gulf of Mexico to avoid Hurricane Ivan. After safely arriving at its intended destination, the crew discovered some portions of the hull had buckled during transit. An engineering team dispatched to the site determined the problem was caused by a previously unknown deficiency in the ship's structure. The Coast Guard ordered all other

ships undergoing conversion to receive corrective hull strengthening modifications. On March 28, 2005, the USCGC Nunivak, which had undergone the requisite hull strengthening, reported a buckling problem that occurred during a normal transit mission. The Nunivak's buckling occurred in a different part of the hull than the buckling the Matagorda experienced. After further analysis, engineers concluded that the cutter had more severe structural inadequacies, mainly due to fatigue and deterioration, than was thought at the start of the conversion process. Inspection of other 110' ships revealed that the problem applied to all ships to be converted. As a result, then-Coast Guard Commandant Thomas Collins stopped the conversion program in June 2005. Commandant Collins cited two principle reasons for this action: First, the hulls of the 110' ships to be converted "were in much worse condition than anticipated. This extended the conversion timeline and would have increased projected costs for conversions after the first eight ... [Second, the CG] identified high risks in meeting mission needs, particularly in the post-9/11 environment" (Teel 2007). On November 30, 2006, the eight converted 123-foot ships were deemed unfit for service and removed from the fleet. The Coast Guard ordered the development of the FRC to be accelerated by 10 years to fill the capabilities gap left by the failed ship conversion.

Since the cancellation of the program, several former Coast Guard and LSI engineers have come forward to testify how the LSI and Coast Guard purposefully ignored warnings regarding foreseeable problems. In Congressional testimony Scott Sampson, Chief Development Section U.S. Coast Guard Maintenance & Logistics Command, cited two principal concerns he had with the 123' conversion program that were ignored by multiple managers in the program. First, he feared that the hull of the ship would be unable to accommodate a significant extension of the hull without substantial measures to reinforce the hull. He testified that if the problem were not fixed, longitudinal bending would take place, wherein the force of inertia experienced at the ends of the boat would cause the middle of the hull to either bow up or down. He states that despite his concerns, "no structure was added to the middle of the hulls during the conversion of the 110s" (Sampson 2007). The second concern Sampson raised is known as running trim. The structure of a ship is made to distribute weight evenly along the bottom of the hull, based upon how the ship lays in the water. If too much weight were at one end of the

boat, the other portion of the ship would not sit on the water. As a result, a smaller portion of the hull would need to support the entire ship, putting considerable strain on the middle of the hull. To avoid this problem, ships to be extended should continue the existing shape of the hull. Sampson stated that the Combat Craft Division, for which he worked, “strongly recommended that the bottom of the extension [to the 110’ ship] actually curve up to reduce its buoyancy. By doing so the trim of the vessel (fore and aft attitude) would remain the same or be very similar to the 110’s” (Sampson 2007). The LSI chose to have the extension not follow the lay of the original hull. Sampson believed this oversight is the principle reason why the hulls of the converted ships failed. Overall, Sampson asserted that LSI management actively ignored good engineering evidence and only made decisions consistent with their bottom line.

In following Congressional testimony, Philip Teel, President of Northrop Grumman’s Ship Systems sector, defended the actions of the LSI as neither incompetent nor greedy. Teel countered that the hull buckling of the USCGC Matagorda was not due to the LSI’s lack of management but due to the an “inherent workmanship issue in the baseline 110’ that existed prior to the conversion and contributed to the hull buckling. Specifically, a hidden, unwelded aluminum deck stringer was discovered immediately beneath the area where the failure occurred ... [which the Coast Guard’s investigating engineering] team believed ... to be the primary cause of the buckling” (Teel 2007). The Coast Guard decided to proceed with development at this point because the LSI’s updated risk models, which included several modifications, still showed their design to be sufficient. Going further, Teel argues that the hull buckling of the Nunivak was “in an area aft of the new reinforcing straps. This deformation occurred in a different area from that of the Matagorda. Further, this was not an area which had indicated potential for high stresses under any conditions modeled in the earlier finite element analysis” (Teel 2007). A more comprehensive test of the Coast Guard’s 110-foot ships took place at that point in time, which subsequently revealed that the ships had significantly more structural damage than originally estimated. Using this new information, the Commandant decided to cancel the program in 2005 for the reasons stated above. In sum, Teel argued that the failure of the program was not based on their ship extension design but on faulty information regarding the preexisting structural deficiencies of the 110’ ships.

Fast Response Cutter

In its 2005 Revised Deepwater Implementation, the Coast Guard accelerated the development timetable of the FRC by 11 years, advancing the delivery date from 2018 to 2007 (GAO 2008b). The Coast Guard believed, in light of the failed 123' conversion program, that the best course of action to fill the short-term dearth of capabilities would be to field the long-term solution as quickly as possible. The FRC development project soon faced technical problems that led to schedule delays and cost overruns. Most of these problems arose from the LSI's use of a composite hull for the craft, as opposed to traditional steel. The LSI believed that the composite hull would offer substantially lower maintenance and lifecycle costs along with a longer service life than a steel equivalent. The LSI cited the use of composite hulls in both military and commercial vessels as a precedent. The composite material the LSI design produced, however, was unable to yield the advantages that the modeling predicted. Although the composite material was much heavier than steel, it was not as strong or durable as first thought, ultimately necessitating thicker hulls than first intended. The composite hull received further criticism from Navy officials who, after testing the material, concluded that the hull was very unlikely to last for its intended lifetime. As a result, "in February 2006 the Coast Guard suspended FRC-A design work in order to assess and mitigate technical risks" (GAO 2008b). Again concerned about fulfilling a needed capability quickly, the Coast Guard decided to pursue a dual development track for the FRC. The FRC, renamed the FRC-A, would develop at its own pace. Simultaneously, the Coast Guard would develop a second FRC, unrelated to the first, named the FRC-B. This craft would utilize an existent commercial ferry as its basis, in a development strategy known as commercial-off-the-shelf technology, to reduce costs and speed delivery. In April 2006, the Coast Guard issued a Request for Information regarding the development of the FRC-B. A Request for Proposal (RFP) was subsequently submitted in November. The RFP "requires the lead cutter produced under the contract to be delivered within 730 days after contract award [spring 2010] ... Although the intent is to buy 12 boats under the FRC-B contract, the wording of the RFP gives the Coast Guard the leeway to buy all 58 of the expected FRC class" (Kreisher 2007).

The Coast Guard planned to award a contract for FRC-B, renamed the Sentinel-class Patrol Boat, in July 2008. The contract was awarded in September 2008 to Bollinger Shipyards, Inc. Marinette Marine corporation, a competitor for the contract, filed a protest with GAO in early October 2007. On January 12, 2009, the GAO upheld the original award decision. Exact details regarding the case have yet to be released (U.S. Coast Guard Acquisition Directorate 2009).

The option to buy all ships of the FRC class was included as a safeguard against continued development difficulties with the FRC-A. As feared, the FRC-A continued to face development troubles. In March 2007, the Coast Guard withdrew from its contract for the FRC-A; the program was subsequently terminated in February 2008.

Coast Guard takes over LSI responsibilities

In April 2007, the Coast Guard relieved the Lockheed Martin-Northrop Grumman partnership of LSI responsibilities citing poor performance. As noted in one article, “the need for new assets grows ever more urgent as costly repairs on legacy assets continue to eat away at the funds available for a recapitalized fleet” (Munns 2007). The Coast Guard has since assumed the systems-of-systems integration responsibilities. The Coast Guard has altered the management of the Deepwater project, including a “reorganized acquisition directorate, a shift to acquiring Deepwater assets individually as opposed to through a system-of-systems approach, and efforts to improve information to analyze and evaluate progress” (Hutton 2008). The Coast Guard has moved towards a more traditional asset-by-asset acquisition strategy for most assets. Deepwater still maintains a SoS approach, however, for those assets that extend across the project, such as the information network. Despite the Coast Guard’s displeasure with the Lockheed Martin-Northrop Grumman team, it has retained the partnership as the primary contractor and principal development partner. Two months after relieving the partnership of LSI duties, in June 2007, the Coast Guard awarded the partnership a “43-month extension of the Deepwater modernization contract with one large caveat—that the service can review the team’s performance at 18 months and decide whether to continue the full 43 months” (Kime 2007). Reflecting the Coast Guard’s dependence upon the partnership and lack of

qualified staff to man all management positions, many private contractors continue to fill important vacancies within the Deepwater development project. As noted by a recent GAO report, "the Coast Guard is experiencing vacancy rates of almost 20 percent" (GAO 2008c). The effect of these managerial changes cannot be evaluated at this point, however, due to insufficient information.

Criticism of Deepwater

Criticism of Deepwater program centers on two issues. First, Deepwater did not follow a knowledge-based acquisition strategy. Second, the Coast Guard failed to properly oversee the project management by the LSI. Combined, these problems undermined the development of the SoS project.

Lack of a knowledge-based acquisition strategy

Deepwater, like many other military and security acquisition projects, did not follow a knowledge-based acquisition strategy. As noted by one critic, some of Deepwater's problems reflect systemic problems with the acquisition process as a whole that perpetuates a vicious cycle: "Program requirements... are set at unrealistic levels, then changed frequently as recognition sets in that they cannot be achieved. As a result, too much time passes; threats may change; and/or members of the user and acquisition communities may simply change their minds. The resulting program instability causes cost escalation, schedule delays, fewer quantities, and reduced contractor accountability" (Caldwell 2007). GAO and other outside organizations have frequently cited the DoD for starting development of assets based on unproven and immature technologies. When these technologies do not develop as hoped for, the entire development project is in jeopardy. Ultimately, the end user receives less than promised in capability, pays more for the weapon than necessary, and must wait a considerable amount of time for deployment. With regards to Deepwater, a number of audits existed prior to and during the development noting the project's inherent risks. These risks included the use of immature and untested technologies as the basis for Deepwater assets and the project's accelerated schedule.

Lack of adequate oversight

The Coast Guard's substandard oversight of the LSI's management also contributed to major development problems. Without sufficient oversight, problems were not caught at an early stage of development; costs have mounted as the later in the development process asset modification occurs, the higher are associated costs. The Coast Guard failed to provide adequate oversight for a number of reasons. First, critics have often cited "unfavorable contract terms and conditions, poorly defined performance requirements, and inadequate management and technical oversight ... [along with] vague contract terms and conditions [as having] compromised the Coast Guard's ability to hold the contractor accountable" (Skinner 2007). Differing interpretations of managerial responsibilities and even key performance requirements have undermined accountability. Second, the Coast Guard has lacked the people and technical ability to ensure proper oversight. As noted above, the acquisition force does not currently have the size or capability to oversee the management of a project as large and complex as Deepwater. The Coast Guard was unable to man all of its positions even when the LSI was principally responsible for managing the development of Deepwater. Finally, in at least some instances, negligence was the cause of lapsed managerial oversight. For example, in the middle of November 2006 Congress discovered that "the Coast Guard withheld from Congress warnings raised more than two years ago by its chief engineer about structural design flaws in its new National Security Cutter" (Lipton 2006). Although the Coast Guard was aware of concerns regarding the development of certain Deepwater assets, it did not seek clarification or modification at that point, leading to subsequent schedule slips and cost increases along with strained relations with Congress.

Even though the Coast Guard retained authority over the Deepwater project, the Coast Guard was unable to properly oversee the LSI's management effort. As noted by current Coast Guard Commandant Thad Allen, although the LSI had considerable authority to meet Coast Guard requirements "the Coast Guard has been and remains fully involved in the management of this program and has made all final and critical decisions" (Allen 2007). The LSI expressed a similar understanding of the situation when Teel stated "the U.S. Coast Guard is the decision making and contracting authority, and has retained the

traditional contract management functions, including the right to issue unilateral change orders, to stop or terminate work, to order or not order assets and supplies, and to accept or reject the work” (Teel 2007). The lack of oversight reflects the reality, as Commandant Allen stated, that “unfortunately, we in the Coast Guard didn’t adequately reorganize ourselves to interface with, and oversee, the contractor team” (Kitfield 2008).

Mitigating Factors

Several factors should mitigate the criticism against the Deepwater project, however. First, the program faced an unprecedented challenge in Coast Guard history of fielding an entire fleet of assets simultaneously. Under any circumstances, the development project was likely to be difficult, as no SoSE blueprint existed. In many ways, SoSE was being learned on the job, as development was progressing. Second, the project experienced significant increases in requirements along with an accelerated acquisition timetable after development had already started. Any redesign after initial development would be costly. The accelerated timetable left the project with little margin for error. It was nearly impossible for a project to get back on track when problems occurred. Third, the Coast Guard used “undefinitized contract actions (UCAs) ... a legal vehicle that allows production to continue after a design change, even though the parties have not formally negotiated the full price and terms of that change” (Brown). In this way, the Coast Guard prioritized program schedule over stability, but in the process lost some of its leverage to negotiate the cost of the modification. Problems that could arise from the use of UCAs were likely exacerbated by the inconsistent understanding of roles and responsibilities among the participants of the LSI contract. Finally, the Deepwater project received unusually high political visibility because its first major goal—the 123’ conversion—failed so spectacularly. As Commandant Allen noted in an interview, “after we made the very difficult decision to take those ships out of service, it became a litmus test of our perceived competence to manage the entire Deepwater contract, and [lawmakers] questioned the role we had assigned the contractors as the lead systems integrator” (Kitfield 2008). It is difficult to disseminate how political factors may have consequently influenced the project.

The Army's Future Combat Systems

The Army's Future Combat Systems (FCS), a SoS development, is the "Army's first full-spectrum modernization in nearly 40 years" (US Army 2007). The FCS originated as the combat portion of the Army's 2003 planned Future Force and had the overarching strategy to prepare the Army for operation in the next century. The goal of this system was to "free ground warfare from the tyranny of terrain" (Scales 2006). The Army believed that the new NCW doctrine would be critical to the development of a new agile and mobile force. The heart of the FCS SoS is an integrated information network that enables FCS assets to respond more rapidly to changing battlefield conditions and in a more coordinated manner than any opponent. In this way, the advanced information network is a force multiplier by providing military personnel full battlespace awareness. Ultimately, the Army believes FCS will support NCW and offer the service a force that is more responsive, more integrated and more sustainable than the current force. Moreover, this force would attain greater lethality and survivability than current forces, while using fewer resources.

The Army was prompted to develop a more responsive force due to the emergence of asymmetric warfare as the principal fighting method during the 1990s. The Army determined that the army of the future, FCS, must embody two important changes. First, the Army needs to be much more deployable. Currently, deploying one of the Army's heavy brigades requires several months of planning and transportation. FCS needs to be deployable within weeks or even days. Second, Army assets must remain light and maneuverable without sacrificing firepower to effectively counter both conventional and asymmetric threats. In order to accomplish this objective, FCS must be a system equipped as a light brigade with the



capabilities of a heavy one. The FCS's ultimate goal is to "replace mass with superior information allowing soldiers to see and hit the enemy first, rather than to rely on heavy armor to withstand a hit" (GAO 2007a). The FCS concept relies upon the use of superior technology and information to identify and engage the enemy at stand-off range before the enemy can locate FCS assets. An advanced information network is crucial to realizing these twin goals.

An advanced information network will increase the capabilities of the ground forces by providing soldiers with full battlespace awareness. Each fielded FCS component, including the soldier, will act as a sensor on the battlefield. Information will be seamlessly transmitted across the network, both up and down the chain of command, to every other participant in the field, as well as to the command post. The jointness of the information systems will not only allow a commander to issue orders to a soldier, but it will also enable the soldier to give up-to-the-second feedback to other assets in the area. Together, this information will allow the Army to achieve the FCS's motto: "see first, understand first, act first, finish decisively" (Boeing Integrated Defense Systems 2006).

In addition to achieving a decisive edge in combat, the Army believes that FCS will significantly reduce operational resources. Through purposeful intent, SoS development in FCS will increase the tooth of the force while minimizing the tail. As stated by The Future Combat Systems Smart Book (September 2006), the Army hopes to achieve: "70-90% vehicle commonality [resulting in a] 60% reduction in mechanics, ... 50-70% reduction in force size and fuel consumption [and] ... 60% more strategically deployable than Current Forces" (Boeing Integrated Defense Systems 2006). Each FCS brigade will require fewer troops than existing units while providing more combat soldiers and will require fewer resources to operate and be more easily deployable.

Future Combat Systems Assets

FCS was originally planned to field a system comprised of 18 weapons platforms, the soldier, and an information network. However, Congress initially funded only 14 of these weapons systems. The Army has dubbed this configuration “14+1+1”: 14 weapons platforms, plus the advanced information network, plus the soldier. The 14 platforms include eight manned ground vehicles, two unmanned ground vehicles, two unmanned air vehicles, the non-line-of-sight launch system, and unattended ground sensors. Figure 4 provides a more detailed description of the systems that comprise FCS.

Future Combat Systems Funded Assets		
Type of Asset	Name of Asset	Description
Manned Ground Vehicles	XM 1201 Reconnaissance and Surveillance Vehicles (RSV)	Advanced sensor reconnaissance and surveillance capability
	XM 1202 Mounted Combat System (MCS)	Main battle tank
	XM 1203 Non Line of Sight-Cannon (NLOS-C)	Long-range indirect fire support
	XM1204 Non Line of Sight-Mortar (NLOS-M)	Short-to-mid-range indirect fire support
	XM 1205 Recovery and Maintenance Vehicle (FRMV)	Recovery and maintenance of vehicles in the field
	XM 1206 Infantry Carrier Vehicle (ICV)	Transportation of infantry squads
	Medical Vehicles: XM 1207 Evacuation (MV-E) XM 1208 Treatment (MV-T)	Evacuation of wounded soldiers from the battlefield Treatment of wounded soldiers close to the battlefield
	XM 1209 Command and Control Vehicle	Battlefield command and control capabilities
Unmanned Ground Vehicles (UGV)	XM 1216 Small Unmanned Ground Vehicle (SUGV)	Backpack portable, surveillance UGV for high-risk situations
	XM 1217 Transport MULE (Multifunctional Utility/Logistics and Equipment) Vehicle (MULE-T)	Carry 2,400 pounds of soldiers' equipment
Unmanned Aerial Vehicles (UAV)	XM 156 Class I UAV	Platoon-level, vertical takeoff and landing, reconnaissance UAV
	XM 157 Class IV UAV	Brigade-level, vertical takeoff and landing, surveillance and communications UAV
Unattended Ground Sensors (UGS)	AN/GSR-9 (V) 1 Tactical (T-UGS)	Multi-role sensor system
	AN/GSR-10 (V) 1 Urban (U-UGS)	More advanced sensor suite focused on the urban environment
Non-Line of Sight Launch System (NLOS-LS)	Non-Line of Sight Launch System (NLOS-LS)	Immediate precision guided fire support

Figure 4: Description of funded FCS assets

FCS Schedule

The need to replace aging legacy weapons designed for the Cold War, combined with the need to fill gaps for units currently serving in conflicts in the Near East, prompted the Army to put forth an aggressive timetable for FCS development and acquisition. The original timetable for the program is shown below in Figure 5. Program initiation in 2003 would be followed by the preliminary design review in 2009. Congress will need to make the advanced procurement funding decision in February 2010. Low-rate initial, advanced procurement would commence in 2011, followed by the production decision in 2013. The first FCS brigade would be equipped in 2015, followed by full-rate production in 2017. By 2030, the Army plans to have 15 FCS brigades.

Initial Contract

Soon after the Army publicized its intent to develop a new way of fighting in October 1999, the Army teamed with the Defense Advanced Research Projects Agency (DARPA) to develop what would become the FCS concept. In May of that year, the Army and DARPA selected four contractor teams for an initial 21-month conceptual design phase, each worth \$10 million. The four teams were Boeing Company Phantom Works; Science Applications International Corporation; TEAM FoCuS Vision CONSORTIUM, a joint venture between General Dynamics Land Systems Inc. and Raytheon Company; and Team Gladiator, a joint venture between TRW Incorporated, Lockheed Martin Incorporated, Lockheed Martin Vought Systems, CSC/Nichols Research, Carnegie Mellon Research Institute, Battelle Memorial Institute and IITRI/AB Tech Group. During the bid process, in January 2002, two of the FCS bidders, Boeing and SAIC, decided to team and issue a joint bid. In March 2002, the Army awarded this partnership a LSI contract for the FCS' concept and technology development phase. The LSI was expected to make a \$154 million profit for the 16-month effort (U.S. Department of Defense and DARPA 2002). DARPA and the Army originally planned to evaluate in April 2003 to determine whether technologies were mature enough to proceed with further development. The Army specifically granted the prime contractor, Boeing, system-of-systems integration responsibilities because it did not believe that it had the

inherent capability to manage the SoS project by itself. Due to the arising security concerns (due to 9/11), the Army immediately began to develop the program. In May 2003 they selected the Boeing-SAIC concept to proceed into the System Development and Demonstration phase (Boeing Integrated Defense Systems 2003).

The Army and Boeing eventually signed an “Other Transaction Authority” (OTA) contract for the Systems Design and Development (SDD) phase in December 2003. To provide the program with greater flexibility, the Army opted for a non-standard contracting instrument known as an OTA agreement, which is not subject to the Federal Acquisition Regulation (FAR). Congress intended OTA, established in 1994, to be used for research, development and prototyping with small innovative companies that were not part of the defense industrial base. Many of these small companies were previously excluded from competing for DoD contracts as they did not have the infrastructure to abide by the onerous reporting requirements of FAR. The initial contract was for the first increment of the \$91.4 billion program, 17-year project (Francis 2006). The agreement was a cost-reimbursement agreement for the first \$14.8 billion development. This agreement included a “10% fixed fee, plus up to 5% in incentive awards—[for] a total of \$2.2 billion in potential profit” (Cook 2005).

The LSI was originally contracted to direct and manage the entire development process. The Boeing Company would also be responsible for two important software-intensive subsystems: System of Systems Common Operating Environment (SOSCOE) and the Warfighter Machine Interface (WMI). SOSCOE is described as the operating system of FCS. This system is being developed by the LSI, which the OTA agreement permitted to “internally develop SOSCOE rather than contracting that work out to a separate supplier” (GAO 2007b). WMI is to provide an “integrated presentation of all types of battlefield information” (GAO 2007b). Through competitive subcontracting, the LSI awarded WMI to a separate Boeing operational unit.

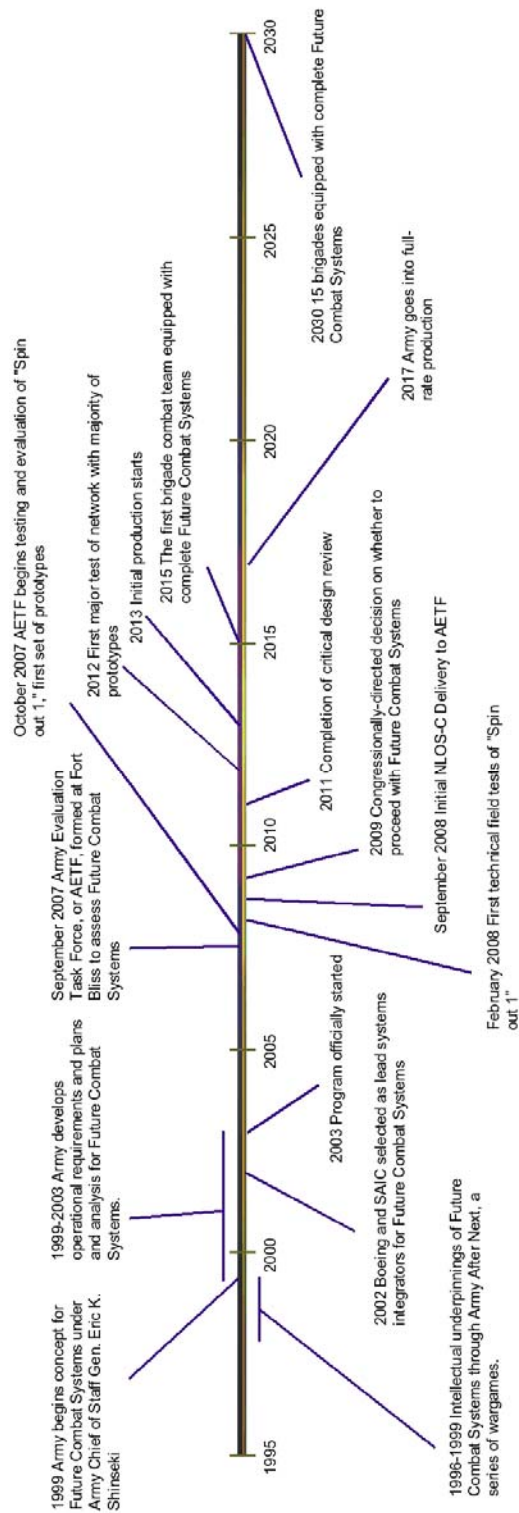


Figure 5: Future Combat System Acquisition Timeline (U.S. Army 2008)

Army Established Tenets Prior to Development

Perhaps uniquely, the Army established early in the process a clear list of goals it wished to accomplish for the FCS project. This list includes

- Create opportunity for best of industry to participate;
- Leverage government technology base to maximum extent;
- Associate ongoing enabling effort with LSI-led activity;
- Maintain a collaborative environment from design through lifecycle;
- As a minimum, achieve commonality at subsystem/component level;
- Design/plan for technology integration and insertion;
- Maintain and shape the industrial base for the future;
- Retain competition throughout future force acquisition;
- Have appropriate government involvement in procurement processes;
- Achieve consistent and continuous definition of requirements;
- Maintain and shape government and acquisition community;
- Achieve program affordability, balance performance and sustainment; and
- Have a “one team” operating partnership and teamwork.

(GAO 2007b)

Although this detail has not received much attention from the media, Lieutenant General Joseph Yakovac, the former Military Assistant to the Assistant Secretary of the Army for Acquisition, Logistics and Technology (2003-2007), believes “these tenets became the foundation for the contract as well as the management relationships that exist today between all government players and the Lead Systems Integrator” (Yakovac 2007). By creating a shared vision, the Army and LSI have been able to function as a team that can respond effectively to rapidly changing circumstances while avoiding internal disharmony.

FCS Restructurings

First Program Restructuring

FCS has faced significant development difficulties exacerbated by federally mandated changes to the system. As a result, the program has been reorganized twice. The first

restructuring took place in July 2004 and expanded the scope of FCS by fully funding all 18 platforms originally envisioned by the FCS concept. This restructuring also created a spiral development framework that included four distinct spirals to field new technology to troops faster. The Army reorganized the program for two reasons. First, following 9/11, Congress increased funding for DoD development programs that allowed programs, such as FCS, to pursue more ambitious capabilities (Boeing Integrated Defense Systems 2004). Second, the Army and Congress desired incremental fielding of assets to respond to challenges troops faced in the ongoing conflicts in Afghanistan and Iraq. Under the spiral system, assets will be fielding more quickly to the troops, with the first increment deploying in 2008. Proponents of Spiral Development acquisition strategy also believed it would enhance the program's flexibility, enabling the developer to avoid technological bottlenecks that hampered other programs.

Contract Restructuring

During 2005, the structure of the FCS contract was also changed. Under pressure from Senator John McCain (R-AZ), the Army agreed in April to restructure the contract vehicle from OTA to a FAR-based contract. The Congress was particularly concerned by the lack of oversight into the large program, the high fixed-fee of the original contract, and the scaling of the fee to increases in the price of the contract. As noted, "when the initial cost grew by \$6.4 billion, Boeing got 15% for that increment, too, for \$960 million more in potential profits" (Cook 2005). Congress believed that this contract did not provide sufficient incentive for Boeing to keep development costs low, as an increase in the price of the program would actually increase the overall profits of the company, all at the expense of the taxpayer. The Army and Boeing signed a new FAR-based contract on September 23, with a fixed fee of 3% and an incentive award of up to 12%.

Conflict of Interest Provision

The new FAR-based contract also instituted an Organizational Conflict of Interest (OCI) provision to mitigate the LSIs' potential conflicts of interest. The provision has two important impacts. First, the LSIs are "prohibited from competing for work under the SDD contract at any tier" (Toenjes 2008). Second, contractors are prohibited from

participating in source selection “if any part of its organization submits a proposal” (Toenjes 2008). Subcontracting agreements made prior to the restructuring of the contract remain in effect. The goal of these provisions is to eliminate the potential conflict of interest that would arise for a large company, such as Boeing or SAIC, to circumvent competitive subcontracting by awarding other divisions of the parent company contracts to develop a platform.

Cost and Schedule Changes

In 2006, the Army issued new cost and schedule estimates once it became apparent that the first restructuring would run significantly over budget and under schedule. The new estimate increased the total cost of the program from \$91.4 billion to \$160.7 billion, a 76% cost increase, while the program extended from 2020 to 2026 (Child 2005). The increase in cost was attributed to the increase in the scope of the project and technical development problems.

Second Program Restructuring

A second restructuring took place in early 2007. The principal goal of this restructuring was to maintain program costs within the new funding levels established in 2006. This restructuring both reduced the scope of FCS and reorganized programs within FCS. Program costs increased as a result of adding additional spin-outs of capabilities to current forces, extending the development rate and including the previously unrecognized ammunition costs for FCS. Costs were reduced by deleting or deferring four systems—the Class II and III unmanned aerial vehicles, the intelligent munitions system, and the armed robotic vehicle—changing (often reducing) the number of individual system assets to be purchased; and reducing the production rate for assets. The Army believes that costs have been maintained since this second restructuring, while some outside sources cite substantially higher estimates.

Why the Army chose a private LSI

The Army chose to use a private LSI because it did not believe it had “the workforce or flexibility to manage development of FCS on its own within desired timelines” (GAO

2007b). The Army, in line with other government acquisition forces, believed that it lacked critical expertise and capability in key areas. For example, the Army did not believe it had enough software engineers to develop the information network; the managerial flexibility to respond to changing circumstances; the ability to effectively coordinate effort across the traditional organizational lines of the DoD, required for full network integration of the military; or enough capability to staff and manage a program as large and complex as FCS (GAO 2007b). Under the traditional acquisition system, each of the 14 individual weapons systems along with the network would have been considered a major defense acquisition program. The Army put forth a demanding timetable for FCS development because it believed that the new challenges faced by the military must be met as quickly as possible. Due to the aggressive development timetable, the government would have insufficient time to reconstitute its own acquisition workforce. FCS could only be realized by partnering with a private firm to help oversee and manage development. The DoD concluded that LSI would be the most effective answer to the problem.

The FCS's development motto is "One Team-The Army/Defense/Industry." The Army believes the embodiment of this maxim will yield advantages to the development process not attained by other programs. Conversely, the Army believes that partnership is the only way FCS can be realized: the motto "illustrates the unprecedented level of Army, Department of Defense and defense industry partnership that is integral to the program and on which success depends" (Steele 2005). Cooperation requires the Army and LSI to act as partners on the program. The Army is responsible for making final decisions regarding development and providing appropriate oversight over the entire program. The LSI, which has been granted extensive responsibility for SoS development, is responsible for fielding a best-of-industry effort to develop FCS. The LSI's activities include consistent and continuous definition of requirements, development of technology, source selection, administrative coordination and management of the allotted budget.

Criticism of LSI relatively muted

The Government Accountability Office (GAO) has criticized the FCS development process for a number of reasons, most notably for lacking a knowledge-based acquisition approach. Although GAO is critical of FCS development, its reports are relatively silent regarding blame that should be allotted to the LSIs for problems that have occurred during program development. Acknowledging the difficulty of the situation, the GAO states candidly,

We have expressed concern that the FCS program moved forward with insufficient knowledge and, therefore, an insufficient business case. However, that aside, if one accepts the FCS program for what it is and where it is in the development cycle, the Army has set up a contractual relationship that is both consistent with this vision for FCS and candid with respect to its workforce limitations. The Army has been thoughtful about what it is trying to accomplish collaboratively with the LSI, and has been working hard to make progress, including facing up to difficult tradeoffs. On the other hand, the limits of the contractual arrangements must also be recognized. Given the unprecedented challenge FCS represents, it is unrealistic to expect that any contracting approach alone could assure a successful outcome. Ultimately, the risks of successful outcomes will be borne by the government. The contractual arrangements are not a substitute for having the high level of knowledge that a sound business case requires. (GAO 2007b)

Few sources have criticized the function of system-of-systems integration as detrimental to the development program. Sources acknowledge that, although the LSI has faced difficulties, the Army still requires a single entity to perform systems-of-systems integration functions—a function it cannot currently fulfill easily—if it still wants to pursue SoS development. On the whole, the feared concerns regarding use of a LSI have not come to fruition. Although the LSI has not performed perfectly, the LSI has helped facilitate successful program development, despite the numerous obstacles since program initiation in 2003. Successes of the program include acceleration of the program from the

envisioned 2015-2020 range to 2010, implementation of spiral development along with four spirals to troops in the field while remaining on budget and on schedule. Moreover, the program yielded opportunities for best-of-industry effort with effective government oversight, as “all major subcontractors on the program were competitively selected by a combined LSI/government team, with the Army's Acquisition Executive as the final approval authority” (Yakovac 2007). Whether or not the government utilized safeguard measures to ensure the interests of the government, and ultimately the tax payer, were upheld consistently is debatable; measures to ensure the government could pursue rigorous oversight is not.

Epilogue

Recent reports state that the FCS is likely to undergo a significant restructuring following the inauguration of Barack Obama. The restructuring would significantly reduce the scope of FCS, including “cutting out four of the eight manned vehicles” (Tiron 2009). At this point, however, information remains scarce.

Key Lessons Learned

1: SoS integration is widely acknowledged as necessary to pursue SoS development. The presence of a LSI, however, is not a cure-all. Development programs that do not follow a knowledge-based acquisition strategy at program initiation are likely to face cost overruns, schedule delays or reduction in capabilities, regardless of management entity. The military, lawmakers and industry must limit development programs based upon immature technologies to avoid these development problems.

2: The government has final responsibility for all important decisions regarding its SoS programs but has been criticized for not exercising effective oversight of the LSI. Critics charge that lapses in oversight have occurred because the programs have faced certain developmental problems and the government is unwilling to criticize its partners. Although a lapse in oversight of the LSI may be one reason for such problems, a more likely culprit is the overall system that encourages optimistic assumptions of technology development that fails to attain its desired goals. Nonetheless, the critic's point is valid:

the government should provide no doubt that its relationship with the LSI infringes upon the successful development of the program. The government must provide proper oversight by filling outstanding vacancies, ensuring a high level of technical capability among its acquisition workforce along with proper motivation for all to do their best.

3: It is important for the government and industry to establish key shared interests early in the development process. These tenets create a unified goal and purpose that provides the foundation of the partnership that will persist throughout the program. The commonality of objective encourages the two entities to work on the same side of the issue as opposed to being in opposition to one another. Ultimately, this process helps foster a strong partnership. This theory has been granted some credence by the relative success of FCS, which implemented this process, in comparison to Deepwater, which did not pursue this process; for example, many “Army and LSI program managers ... [believe] that the successful and timely restructurings of the program since 2003 would not have been possible” (Yakovac 2007) without the strong LSI partnership.

VI. Findings, Recommendations, and Conclusion

The government, in particular the DoD, has pursued SoS development in order to address several needs: transition to a more capable net-centric force, modernize aging equipment and respond to the new threat environment that exists after 9/11. SoS would also provide, through synergistic and emergent behavior, the benefit of a force multiplier effect.

The government agencies realized that these complex SoS programs were unlikely to achieve the desired results unless a single entity had the authority and responsibility to coordinate the development effort in order to achieve the desired end capability. Understanding that it lacked the inherent capability to do the job itself, the government contracted a private LSI to help manage the SoS development process.

The LSI, like a traditional prime contractor, must oversee the technological maturity, subsystem development and make decisions regarding tradeoffs within the context of the entire program. The LSIs, however, were also given broad authority to execute these programs that included development of individual system requirements, contracting for their development and procurement, and coordination of development schedule and effort. A LSI may have additional government-like responsibilities including technology development, testing, validation, procurement and sustainability. The degree of authority and responsibility given to a LSI, however, depends upon the program in question.

The use of a private LSI presents several formidable challenges to the government. We believe, however, that the government—as long as it wishes to pursue SoS development—must overcome these obstacles.

Findings

1. **The military is committed to SoS development.** At present, the DoD is firmly committed to the NCW Doctrine, which requires increasing integration of intelligence sensors and weapon systems. As a result, traditional platform-centric development of weapons systems is becoming increasingly impractical, especially

when contrasted to SoS development; the DoD is unlikely to abandon this development scheme.

2. **SoS engineering and integration is a complex undertaking.** The interconnected nature of SoS development presents a prominent challenge to any SoS integration effort. With a single system, tradeoffs between weapon attributes may have to be considered. However, when dealing with a SoS, decisions made about individual components or systems may have ripple effects upon the other sections of development. If one component of a single vehicle cannot perform a task or becomes more expensive, the whole system of systems may need significant revision. For instance, if the development of smart artillery munitions is delayed indefinitely, decision-makers must determine whether reliance on pinpoint-accurate artillery fire significantly impacts the functioning of the SoS as a whole. If so, wide-ranging decisions may have to be made, such as significantly increasing vehicle defensive armaments, which may change the forces maneuverability, and so on. No matter how capable a LSI, SoSE presents a challenging and demanding task.
3. **SoS development is still a maturing discipline.** As a result, the government's acquisition workforce does not have a consistent understanding of SoSE, and perception of the term and its implications varies widely. In the survey listed above, few practitioners correctly differentiated SoSE and traditional engineering. SoS implementation is further hindered by the lack of a codified approach to SoSE.
4. **Government does not currently have capability or capacity to perform SoSE.** At present, the DoD does not have the human resources capability to successfully perform the extensive systems engineering and integration tasks required by SoS. In order to perform these functions, the DoD would need to reconstitute its engineering and technical management capabilities. Doing so would require a considerable investment of time and resources. Even if successful in the short term, the government would have difficulty maintaining a cutting-edge

workforce, as the private sector offers higher wages to workers and generates most of the technical innovation, especially in rapidly-evolving computer and software fields. The government's ability to direct a SoSE program is also hindered by an entrenched culture that often resists collaborative and integrative efforts.

5. LSI programs have experienced technical difficulty for a variety of reasons.

First, programs have experienced requirements growth in response to expanded mission profiles. Second, in response to operational requirements, programs were accelerated—often based more on optimism than best engineering practices, resulting in development problems. Third, the current conflicts in Afghanistan and Iraq have led to a restructuring of programs, in an attempt to provide capabilities to soldiers in the field as quickly as possible. These attempts to accelerate programs have resulted in some development problems. Finally, recent programs have started without a sufficient knowledge base. SoSE programs are complex endeavors. Again, the failure of one platform can have negative ripple effects upon the entire SoS, resulting in the redesign of other platforms.

6. Despite retaining final decision authority, the government has not consistently provided effective oversight of private LSIs.

It is difficult to discern to what extent lax oversight has stemmed from the government's inability or unwillingness to fulfill its obligations. Some problems have arisen from vague contract language conditions delineating authority and responsibility.

Government and private industry did not fully understand their new contractual responsibilities when undertaking a LSI contract. In practice, government contracts have tended towards the extremes: complete control by the government or complete control by the firm. These problems were compounded by the government's lack of capability to fully staff its oversight positions.

7. The greatest concern regarding the use of LSI is the government's delegation of "inherently governmental functions."

Many policymakers, acquisition officers and members of the public feel that the government retreats from its

responsibility when it contracts a LSI to manage acquisition programs. Fears are highlighted by the government's demonstrated challenges with the management of the LSI contracts. The government will continue to face criticism of the private LSI contract as long as LSIs are seen to infringe upon what many believe are inherently governmental functions.

8. **A potential conflict of interests exists for private LSIs.** Current LSI contracts are with major defense contracting firms that provide both management and development functions for SoS programs, since the large independent systems engineering firms no longer exist (they have been mostly acquired by U.S. primes). These primes have innate incentives to benefit their own company, and since much of the profits will come from the production and support of systems, a firm has significant incentive to subcontract to itself or its exclusive subsidiaries. Persons or firms may not undertake such action consciously, but rather, they should be based on their greater knowledge of, and familiarity with, close corporate affiliates. If not controlled, these actions potentially degrade the SoS capability, as well as increase the program cost.
9. **Unified leadership of the system-of-system integration affords the best chance of successful completion.** In 2007, Congress passed the National Defense Authorization Act of Fiscal Year 2008 that prohibits the awarding of new LSIs effective October 1, 2010 (Congress 2008). Despite the prohibition of LSI contracts, development of a fully functioning SoS without a unified effort to undertake system-of-system integration appears unlikely. SoSs are too complex to derive their full potential capability without purposeful planning during the engineering phase. Without a single entity to direct, coordinate, integrate and manage the development of these large programs, SoSs are very unlikely to produce capabilities that are greater than the sum of their parts.

Recommendations

1. **The government should continue development of SoS programs that, if developed correctly, offer the potential for better value—more capability at equal or lower cost—to the military than do individual procurements.**

As long as the government pursues SoS development, an entity will be needed to lead SoS integration responsibilities. A single entity with control over a SoS program is most likely to produce a collection of platforms that function effectively as an integrated unit to produce results that are greater than the sum of its parts. At present, the government does not have the capability to reliably pursue lead systems integration by itself.

2. **The government must effectively partner with the private sector to adequately perform the LSI function.**

At present, private firms are the only entities able—due to their scale, capacity, and flexibility—to do the necessary systems engineering for SoS. However, as opposed to a LSI contract, we propose a partnering in which the government retains oversight of critical requirements and tradeoffs, as well as the source selection of each of the numerous system prime contractors, but closely partners with a contractor for system engineering and integration. We believe the government must implement the following three measures to successfully partner with private industry.

- a. **The DoD must provide better oversight and write contracts that are better defined.** In order to successfully harness the potential of private industry, the government must play a more active role in supervision to enhance effective risk management of SoSE programs. As a partner, the government has the responsibility to ensure the private company fulfills its obligations to develop the best weapon available at the lowest cost attainable. To increase its ability to provide better control and oversight, the government should also write contracts that more explicitly detail the authority and

responsibilities of the government, as well as the contractor, for these SoS programs. Current ambiguities have allowed private firms to acquire more management authority than the government originally intended. Both the government and firm will benefit from contracts that are more clearly written.

- b. **The DoD should accelerate its efforts to recruit, hire, and retain the required human capital required for program oversight (and, when required, program management) for the challenging SoSs acquisitions.**

The government no longer maintains, and is very unlikely to reconstitute, a workforce with all of the engineering skills required to manage new, complex development programs, with only organic resources. However, the government's understaffed acquisition workforce of engineers and program managers may not be adequate to serve its oversight requirement. The DoD must address these human capital needs in order to successfully develop the required SoSs.

- c. **The government should enforce hardware and software exclusion provisions for these system-of-system integration contracts.** Prime contractors performing SoS integration support functions have an inherent conflict of interest that creates perverse incentives that may benefit the company's bottom line at the expense of the government's interests.

- 3. **Congress should modify the prohibition on the use of LSIs to permit either small-scale limited programs for LSIs (or large-scale programs for LSIs who are willing to take hardware and software exclusions), to examine and evaluate strategies to fully leverage private sector capacity, while ensuring adequate government oversight and avoiding conflict-of-interest concerns.**

The DoD does not have sufficient information to evaluate whether use of LSI is realistic or feasible. The use of test programs would allow the DoD to gain a better understanding of the intricacies of SoS development and determine whether a private LSI can be successfully used for SoS development. These limited programs can also be used to incentivize the re-emergence of independent

systems engineering firms (willing to take hardware-exclusion contracts) that could eventually provide the needed support, so that the DoD would not need to rely as much on major defense contractors for large SoS programs.

Conclusion

In the post-Cold War era, the United States faces a diverse set of security concerns. Threats may emerge suddenly and unexpectedly—as highlighted by the terrorist attacks of 9/11. Today, the United States is struggling to transform and modernize its military forces to effectively provide the capabilities required for future security environments, which include threats of both conventional and irregular warfare. The DoD’s need for this modernization is accelerated by the ongoing operations in Iraq and Afghanistan, along with expectations of lower defense budgets in the near future.

In order to overcome these obstacles, the United States needs to implement a development system that is more flexible, more reliable and costs less than the current acquisition system, while still providing needed capabilities to the soldier. SoSs, by design, working as a force multiplier, offer these advantages to the military—but only if SoS development can be implemented successfully. The only way to achieve this goal in the near term is for the DoD to partner with, and leverage, the capabilities of the private sector. Although obstacles to implementation are great, and mistakes have been made, the task can be achieved.

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